Pseudovector Coupling and Charged-Pion Electroproduction

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(Received 17 April 1972)

It is shown that pion electroproduction experiments can, in principle, distinguish between a pseudoscalar and a pseudovector pion-nucleon coupling. It is further shown that this is *not* the case for the corresponding photoproduction experiments.

It is well known that high-energy, forward-direction (peripheral), charged-pion photoproduction processes are dominated by the pion exchange diagram. To this diagram one adds the nucleon exchange diagrams in order to guarantee gauge invariance of the resulting Born amplitude.[1] All these diagrams include a pion-nucleon vertex which is generally taken from pseudoscalar coupling theory.

It is known, however, that a pseudovector pion-nucleon coupling explains quite well some characteristics of the pion-nucleon scattering process,[2] and the question arises whether one should not also apply this theory to photoproduction processes.

We now demonstrate that pion photoproduction experiments cannot distinguish between pseudocalar and pseudovector theories. Let p_i and p_f be the momenta of the incoming and outgoing nucleons, respectively, q the pion momentum, and k the photon momentum, and consider the Born amplitude for $\gamma p \to \pi^+ n$ in the pseudoscalar theory:

$$M_{\rm ps} = ie\sqrt{2}\, g_{\rm ps}\bar{U}(p_f)\gamma_5\left[\frac{(2q-k)\cdot\epsilon}{t-\mu^2} + \frac{1}{\not{p}_f + \not{q} - m}\,\not{\epsilon}\right]U(p_i)\,, \tag{1}$$

where μ is the pion mass, m the nucleon mass, $g_{\rm ps}$ the pseudoscalar pion-nucleon coupling, $e^2 = 4\pi/137$, and ϵ is the photon polarization vector.

In the pseudovector theory one has in addition to the pion and nucleon exchange terms also a contact term arising from the replacement $\partial_\mu \to \partial_\mu - ieA_\mu$ in the pion-nucleon coupling term $\mathfrak{L}_{\pi NN} = ig_{\rm pv}\bar{\psi}\gamma_5\gamma^\mu\psi\,\partial_\mu\varphi$,

$$\mathfrak{L}_{\pi NNA}^{\rm cont} = eg_{\rm pv}\bar{\psi}\gamma_5\gamma^\mu\,\psi A_\mu\varphi\,. \tag{2}$$

The Born amplitude for $\gamma p \to \pi^+ n$ in the pseudovector theory is therefore given by

$$M_{\rm pv} = ie\sqrt{2}\, g_{\rm pv}\bar{U}(p_f)\gamma_5\left[\frac{(2q-k)\cdot\epsilon}{t-\mu^2}(\not{q}-\not{k}) + \not{q}\,\frac{1}{\not{q}+\not{p}_f - m}\,\not{\epsilon} - \not{\epsilon}\right]U(p_i)\,. \tag{3}$$

Since

$$q - k = p_i - p_f\,,\quad \not{p}_i U(p_i) = mU(p_i)\,,\quad \bar{U}(p_f)\not{p}_f = m\bar{U}(p_f)\,,\quad \gamma_5\not{p}_f = \not{p}_f\gamma_5\,,\quad 2mg_{\rm pv} = g_{\rm ps}\,,$$

one easily obtains

$$M_{\rm pv} = M_{\rm ps}\,. \tag{4}$$

This equality breaks down when the various exchange and contact terms are multiplied by *different* form factors, i.e., by the pion form factor $F_\pi(k^2)$, the nucleon form factor $F_N(k^2)$, and the structure function $F_c(k^2)$ attached to the contact term. These functions differ from 1 as soon as $k^2 \neq 0$, i.e., as soon as the photon is virtual, or in other words, as soon as one is dealing with an electroproduction situation. In this case (1) is modified to

$$M_{\rm ps}{}^E = ie\sqrt{2}\, g_{\rm ps}\bar{U}(p_f)\gamma_5\left[F_\pi\frac{(2q-k)\cdot\epsilon}{t-\mu^2} + \frac{F_N}{\not{q}+\not{p}_f - m}\,\not{\epsilon} + (F_\pi - F_N)\,\frac{k\cdot\epsilon}{k^2}\right]U(p_i). \tag{1a}$$

The last term in (1a) is the traditional Fubini-Nambu-Wataghin term[3] added to guarantee gauge invariance also in case $F_\pi \neq F_N$. The pseudovector amplitude (3) is modified to

$$M_{\rm pv}{}^E = ie\sqrt{2}\, g_{\rm pv}\bar{U}(p_f)\gamma_5\left[F_\pi\frac{(2q-k)\cdot\epsilon}{t-\mu^2}(\not{q}-\not{k}) + F_N\not{q}\,\frac{1}{\not{q}+\not{p}_f - m}\,\not{\epsilon} - F_c\not{\epsilon}\right.$$
$$\left. + 2m\,\frac{(k\cdot\epsilon)}{k^2}(F_\pi - F_N) + \frac{(k\cdot\epsilon)}{k^2}\not{k}(F_c - F_N)\right]U(p_i)\,. \tag{3a}$$

The last two terms in (3a) are again modified Fubini-Nambu-Wataghin terms included to guarantee gauge invariance. Utilizing the relations needed for deriving (4), we now obtain

$$M_{\rm pv}{}^{E}=M_{\rm ps}{}^{E}+ie\sqrt{2}\,g_{\rm pv}(F_N-F_c)\overline{U}(p_f)\gamma_5[\not\epsilon-(k\cdot\epsilon)\not k/k^2]U(p_i)\,, \tag{4a}$$

i.e., $M_{\rm pv}{}^{E}\neq M_{\rm ps}{}^{E}$ if $F_N\neq F_c$.

Equation (1a) with some further s-channel resonance contributions was used[4] to analyze recent electroproduction data.[5] With F_N taken from electron-proton scattering experiments it was possible to find $F_\pi(k^2)$ giving a best fit. With Eq. (3a) possessing *two* unknown functions $F_\pi(k^2)$ and $F_c(k^2)$, one may obviously improve the fit. One can then analyze whether $F_c=F_N$ yields the best fit or rather $F_c\neq F_N$.

The last possibility would *definitely* indicate a pseudovector coupling whereas the first one does *not* exclude it.

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Tests of High-Energy Models by Two-Particle Analyses*

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(Received 16 December 1971)

Two-particle distribution functions are calculated in the diffractive-excitation model and compared with those of the multiperipheral model. Optimum regions for differentiating the predictions of the models are indicated. Decisive, yet feasible, experimental tests are suggested.

Among the various models of multiparticle production at high energy,[1] two apparently conflicting ones are the multiperipheral model[2] (MPM) and the diffractive-excitation model[3,4] (DEM). Yet, despite their great differences many of their predictions are remarkably similar, e.g., the logarithmic dependence of average pion multiplicity on energy, and the limiting pion spectra. It is reasonable to expect that the differences between the models are likely to show up in the two-particle correlations among the final particles. Investigations in the two-particle distribution functions have been made[5] with particular emphasis on MPM or Mueller's generalization[6] of it. In this paper we calculate explicitly the two-particle distribution functions in DEM, indicate the restricted regions where the two models differ most strongly, and suggest what crucial experimental quantities to measure.

In terms of the scaled c.m. longitudinal-momentum variable $x=2k_\parallel/\sqrt{s}$ for a single- or two-particle inclusive reaction, we define the (noninvariant) distribution functions to be

$$\rho_1(x)=d\sigma/dx,\quad \rho_2(x_1,x_2)=d\sigma/dx_1\,dx_2. \tag{1}$$

Throughout this paper we shall be interested only in the pion distributions. We have

$$\int_{-1}^{1}\rho_1(x)\,dx=\textstyle\sum_n n\sigma_n\equiv\langle n\rangle\sigma_T\,, \tag{2}$$

$$\int_{-1}^{1}\int_{-1}^{1}\rho_2(x_1,x_2)\,dx_1\,dx_2=\textstyle\sum_n n(n-1)\sigma_n\equiv\langle n(n-1)\rangle\sigma_T\,, \tag{3}$$

$$\int_{-1}^{1}\rho_2(x_1,x_2)\,dx_2\equiv\langle n(x_1)\rangle\rho_1(x_1), \tag{4}$$